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QUANTIFYING HYDROMETEOR ADVECTION AND THE VERTICAL DISTRIBUTION OF CLOUD FRACTION OVER THE SGP CART SITE

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1. Introduction

A single column model (SCM) is, in essence, an isolated grid column of a general circulation model (GCM). Hence, SCMs have rather demanding input data requirements, but do not suffer from problems associated with balance of a GCM. Among the initial conditions that must be used to describe the initial state of the SCM column are the vertical profile of the horizontal wind components and the vertical profiles of cloud water and ice. In addition, the large-scale divergence and advective tendencies of cloud water and ice must be supplied as external parameters. Finally, the liquid and ice cloud amount as a function of height within the SCM column are required for model evaluation.

The scale of the SCM column over which the initial conditions, external parameters, and model evaluation fields must apply is relatively large (~300 km). To quantify atmospheric structure on this scale, the ARM SGP CART site is located within the NOAA wind profiler network and has boundary and extended measurement facilities in an area compatible with the scale requirements of SCMs. Over an area this size, however, there is often rich mesoscale structure. This mesoscale variability creates a sampling problem that can thwart even the most sophisticated attempts to quantify the initial conditions and external parameters, and to evaluate model performance.

There are two approaches that can be used to quantify the time varying quantities required for SCMs: objective analysis and data assimilation. The latter relies on products produced for operational forecasting, while the former involves methods that can be used to combine measurements from various sources to produce synoptic descriptions of the large-scale dynamical and thermodynamic fields. Since data assimilation from operational models introduces the uncertainty of the parameterizations used in the models, most of the focus in the SCM effort has been on developing objective analysis techniques.

A promising variational analysis scheme that produces conservative dynamic and thermodynamic fields from which synoptic-scale advective tendencies in the SGP SCM column can be computed was recently introduced by Zhang and Lin (1997) and tested in a number of SCMs (Cederwall et al., 1998). At present, this variational analysis scheme contains no representation of cloud water or ice. Therefore, a natural step toward further refinement of this variational analysis approach is to develop methods for diagnosing 3-dimensional information about the existing cloud liquid and ice water field over the SCM domain.

While there have been significant advances in satellite cloud retrievals over the past decade, complex, multi-layered cloud systems continue to present a significant challenge, and satellite measurements alone are insufficient to describe the cloud structure over the SCM domain in all conditions. The bulk of ARM's SGP cloud sensing capabilities, including a 35-GHz millimeter cloud radar (MMCR; Moran et al., 1998), are located at the central facility (CF) and sample a narrow Eulerian column. Such measurements can provide quite detailed descriptions of the 2-dimensional cloud structure above the CF, but provide no detail about the 3-dimensional structure over the balance of the SCM domain. Although there are ancillary cloud measurements at some of the boundary and extended facilities, there are no MMCRs from which to determine cloud boundaries, Eulerian cloud fraction profiles, reflectivities, or to perform combined-sensor microphysical retrievals. Therefore, without additional information, the only way to estimate the 3-dimensional cloud structure is to extrapolate the cloud structure observed above the CF over the remainder of the domain using satellite data as a constraint. Given the likelihood of mesoscale variability and complex cloud structure over the SCM domain, such attempts may prove inadequate under many circumstances.

The Weather Surveillance Radar-88 Dopplers (WSR-88D), with their 10-cm wavelength,

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detect inertial subrange turbulence, as well as cloud droplet echoes, because they have a large enough power-aperture product and employ advanced signal processing. Moreover, they are continuously-operating, scanning radars capable of providing 3-dimensional information about the meteorological targets in their measurement volumes. WSR-88Ds are deployed at 161 locations in the United States and abroad, and are distributed throughout the SCM domain and in adjacent SCM columns. The remainder of this paper is a discussion of how this information may be used in the SCM effort.

For meteorological applications, wavelength selection for radars is predominantly target driven, although there may also be hardware or attenuation considerations. Second order scattering mechanisms aside, the predominant targets for meteorological radars are hydrometeors and inertial subrange turbulence. In general, shorter wavelengths are used to detect hydrometeors and longer wavelengths to detect inertial subrange turbulence (the interference mechanism by which these eddies become visible to a receiver is often termed Bragg scatter). As an illustration of extremes, consider 50-MHz wind profilers, with their 6-m wavelength, which detect only refractive inhomogeneities associated with inertial subrange turbulence and receives virtually no echo from precipitation. In contrast, a 94-GHz MMCR receives echo almost entirely from hydrometeors and receives no echo from inertial subrange turbulence. Radars such as 915-MHz profilers and 3-GHz (10-cm) radars, on the other hand, receive echoes from both hydrometeors and inertial subrange turbulence, and ergo require processing techniques or ancillary data to identify the dominant source of the scattering.

2. WSR-88D Products and Data Stream

The WSR-88Ds are operational radars that comprise an essential element of the National Weather Service infrastructure. As such, the operating modes used in the radars are somewhat inflexible with respect to research applications and are often set automatically based on ambient conditions. Pulse-pair processing is used to determine the three moments of the Doppler spectrum: radial velocity, reflectivity, and spectrum width. Because WSR-88Ds operate at 10 cm wavelength, both hydrometeors and inertial subrange turbulence are viable targets and the latter target can be used to compute a clear-air wind profile. While the target reflectivity must meet a threshold before radial velocities are computed, the volumetric radial velocity field can subsequently be used to compute mesoscale divergences (Splitt, 1998). Moreover, it has been shown that the WSR-88D can detect clouds under some circumstances, assuming ancillary data are available to resolve target ambiguities and ground clutter contamination (Miller et al., 1998). If the observed targets are found to be clouds, their advection can be evaluated with the radial velocities.

Data collection and archival for the WSR-88D network is done in tiers and there are three data classes, designated as levels 2-4. Level 2 is the closest to unprocessed base data and is only recorded if the signal is at least 3-dB above the noise level. In addition, level 2 data has already been subjected to ground-clutter suppression. Level 3 and 4 data are fundamentally different than the level 2 data because they have been subjected to more post processing and, most importantly, the reflectivities are binned into 5-dBZ segments (resolution lost). All data with an effective reflectivity factor below 5 dBZ are grouped into a single bin. Since non- or weakly precipitating clouds are known to virtually always have reflectivities less than 0 dBZ, any structural information about the clouds themselves is lost. Assuming the echo from Bragg scatter has been determined to be insignificant, such data may, however, be adequate for use in cloud masking algorithms, and is being used for this purpose by at least one group (Lazarus, personal communication). Hence, to glean specific information about the structure of non- and weakly precipitating clouds, it is necessary to use level 2 data, a laborious task.

The WSR-88D volume coverage patterns (VCPs) describe the combination of scan geometry, transmitter characteristics, and signal processing parameters used to scan the measurement volume. There are four VCPs used in routine operations of the WSR-88D and they are designated as #11, #21, #31, and #32. The VCPs designated as #31 and #32 are sensitive clear-air modes designed to detect inertial subrange turbulence, but can also detect non-precipitating cloud echoes. These two clear-air modes differ from one another primarily by their transmitted pulse widths, and thus measurement resolution, and differ from #11 and #21, the precipitation modes, by their sensitivity and maximum elevation angle. The precipitation modes, VCPs #11 and #21 scan to higher elevation angles and must be used to detect high clouds, but they are not as sensitive as the clear air modes. A complete azimuth scan encompassing 360° is performed at elevation angles ranging from 0.5° to 19.5° for #11 and #21 and 0.5° to 4.5° for #31 and #32. The temporal resolution of a single volume scan is 5-6 minutes in #11 and #21, and 10 minutes in #31 and #32.

3. Spatial Distribution, Logistics, and Detectibility Characteristics of the WSR-88Ds in the SCM domain

There are 7 WSR-88D radars within a 7 degree latitude by 7 degree longitude box surrounding the central facility, as shown in Figure 1. Two of the 7 are Department of Defense (DOD) installations and the remaining 5 are operated by the National Weather Service (NWS), a distinction that becomes important when considering the availability of level 2 data. The oldest of these radars, KTLX, has operated for a period of 6 years, the newest, KVNX, for a period of 4 years, and the average operation period of the WSR-88D radars in the SGP domain is approximately 5 years.

The operating characteristics of each of the SGP WSR-88D radars vary according to local meteorology and operator preferences and, for all WSR-88Ds in the SGP domain, VCPs #21 and #32 are the predominant operating modes as shown in Figure 2a. For each of the 7 SGP radars, the percentage of the time during the total operating life span of the radar for which level 2 archive data are available is shown in Figure 2b. There are two themes that emerge from these data: the level 2 coverage over the northern half of the 7 degree latitude by 7 degree longitude area considered here is superior to that in the southern half, and the NWS installations have a more reliable level 2 archive record than the DOD locations. Particularly disturbing is the 30% level 2 availability at Vance Air Force Base (KVNX), a DOD radar which is the closest site to the central facility.

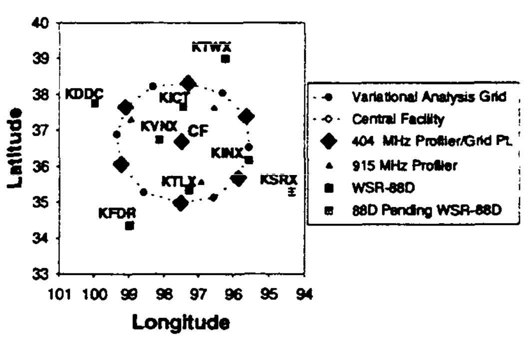


Figure 1. Location of WSR-88Ds in the SGP domain.

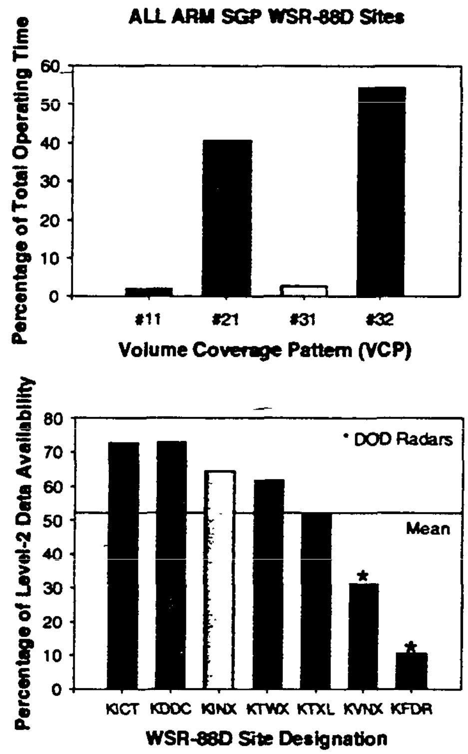


Figure 2. (a) (top). Composite operating modes for all SGP radars and , **(b)**, (bottom) availability of level 2 data for each radar.

From the radar equation and the specifications of the WSR-88D, the theoretical detectibility characteristics may be computed. Since VCP #21 is the prevalent mode of operation in cloudy conditions and has the ability to detect high clouds, it is used for the calculations presented in Figures 3a-c. For these calculations, no beam refraction is considered, deviations from the ideal calibration are ignored, and beam attenuation by atmospheric gases is assumed to be negligible. The effects of beam width and the 3-dB level 2 recording threshold are included. Calculations were made at three vertical levels, 850 mb, 500 mb, and 300 mb, to determine the area over which targets with a reflectivity of only -20 dBZ could be detected.

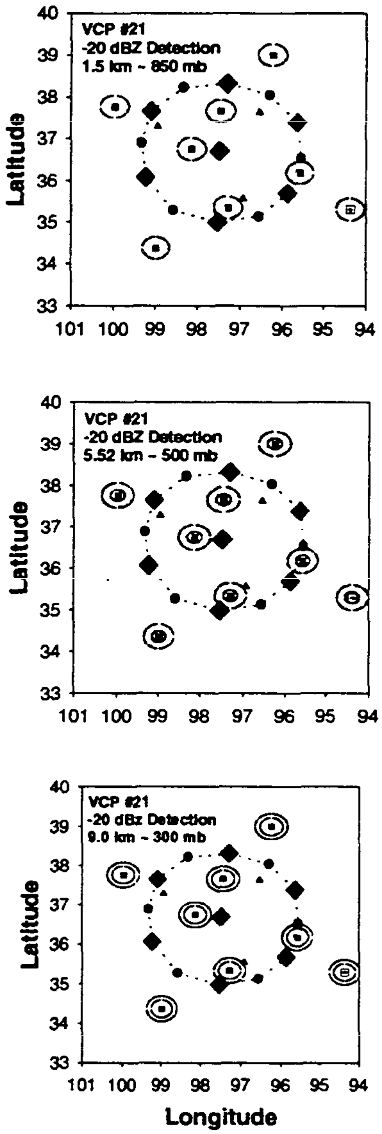
The calculations shown in Figures 3a-c indicate that each WSR-88D can detect -20 dBZ echoes over a relatively small area around the radar site on each pressure surface. As pressure is decreased, the "cone of silence" and the maximum range of detectibility increase at different rates, forming a thin sampling annulus at 300 mb. Inside this annulus the atmosphere is not sampled, and outside it echoes -20 dBZ or less are not detected.

To evaluate non- or weakly precipitating cloud advection at each radar site, data are obtained from the area within the sampling annuli, which is shown to be limiting at pressure surfaces above 500 mb.

3. Summary and Comments

It is possible that the data from the WSR-88Ds in the SGP may provide supplemental information which may, in theory, be applied in the SCM variational analysis. Possible enhancements may include mesoscale wind and divergence (Splitt, 1998), 3-dimensional cloud structure, and hydrometeor advection. With respect to clouds, evidence suggests that domain-wide coverage can be achieved if the analysis is restricted to precipitating clouds (>-5 dBZ), and this may be a reasonable initial approach for incorporating information into the SCM variational analysis.

Detecting non-precipitating clouds over the SCM domain with the SGP WSR-88Ds is a considerably more difficult endeavor. Such an analysis requires the following: (1) the use of level 2 data, (2) a method to separate Bragg scatter returns from hydrometeor returns, (3) careful filtering of ground clutter, and (4) additional information to extrapolate between radar sites and determine cloud base height (weakly precipitating clouds). While such an effort is likely to be taxing, a recent study showed promising agreement between data from a WSR-88D radar and cloud data from a 94-GHz MMCR, verifying theoretical calculations showing that, with limitations, the WSR-88D can detect non-precipitating clouds (Miller et al., 1998). Therefore, it may be possible to retrieve information about the 3-dimensional structure of non-precipitating cloud structure over the SCM column by using the WSR-88D level 2 data in combination with satellite data and data from other SGP sensors. Such information could subsequently be incorporated into the variational analysis to determine if it further improves the performance of SGP SCMs.



Figures 3a-c (top to bottom). Calculations of the areal coverage of -20 dBZ sensitivity at 850 mb, 500 mb, and 300 mb around each of the SGP radars. The outer ring represents the maximum range at which -20 dBZ sensitivity is achieved and the inner ring is the boundary inside which no sampling is possible. Note that the inner ring is too small to be plotted at 850 mb and that the area between the two rings represents the sampling volume for with effective reflectivity factor of at least -20 dBZ.

4. References

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